Development of a Well-Testing Program for a CO_2 Sequestration Pilot in a Brine Formation

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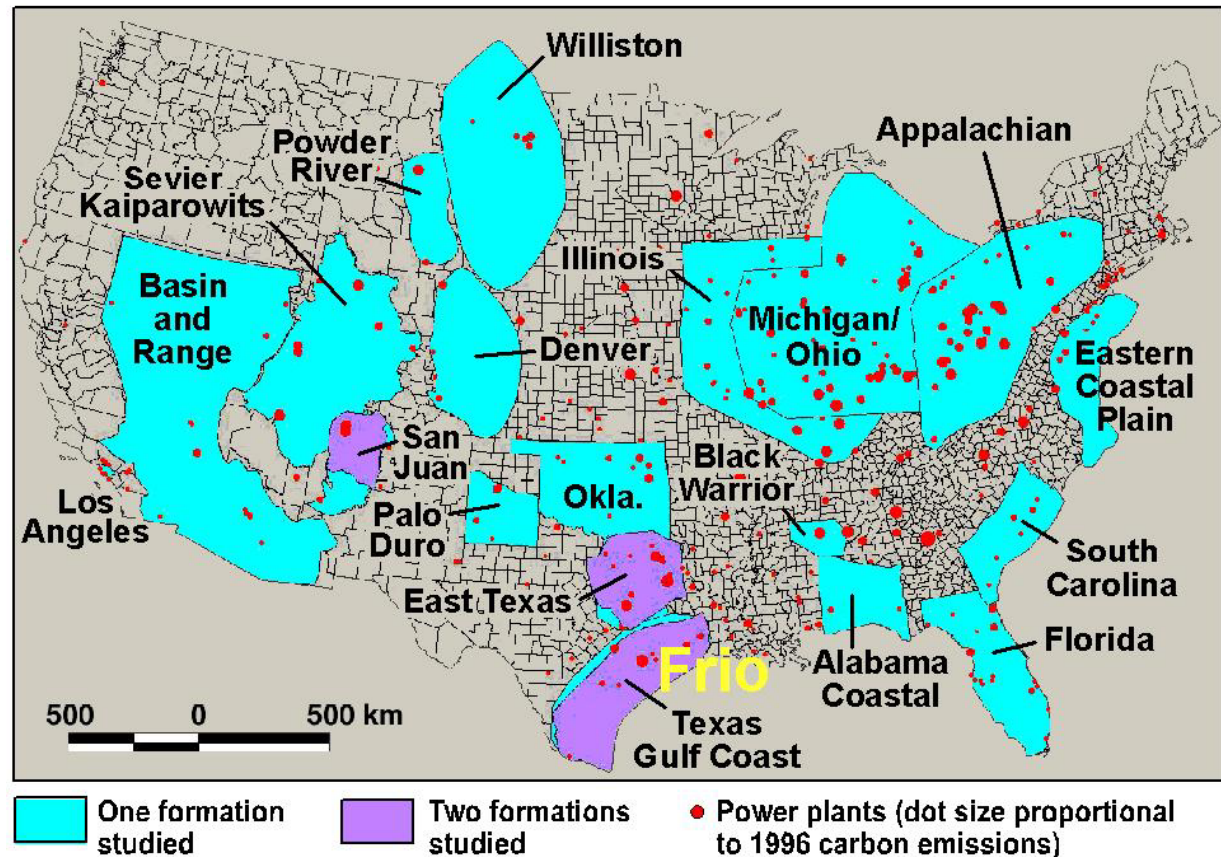
Berkeley, California 94720

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Outline

- **Geologic sequestration in brine formations**
- **Frio CO_2 sequestration pilot**
- **Purpose of well-testing program**
- **Well-test plan**
- **Example simulation results**
- **Conclusions**

Geologic Sequestration in Brine Formations

- **Many localized CO$_2$ point sources**

- **Large volumes of suitable brine formations**

- **Well characterized**

- **Deep-well injection of hazardous waste**

- **CO$_2$ injection technology for EOR**

Williston
Appalachian
Powder River
Sevier Kaiparowits
Illinois
Basin and Range
Michigan/Ohio
Denver
Eastern Coastal Plain
San Juan
Black Warrior
Los Angeles
Okla.
Palo Duro
South Carolina
East Texas
Florida
Frio
Alabama Coastal
Texas Gulf Coast

500   0   500 km

One formation studied
Two formations studied
Power plants (dot size proportional to 1996 carbon emissions)

Frio CO$_2$ Sequestration Pilot

- **Purpose** Demonstrate injection of CO$_2$ into a brine formation with attendant monitoring and modeling to improve understanding of physical and chemical processes
- **Geologic setting** Upper Frio formation, a fluvial/deltaic depositional setting consisting of interleaved high-permeability channel sands and low-permeability shales
- **Applicability** Huge volumes of similar formations throughout upper Texas gulf coast

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South Liberty Pilot Site Structure
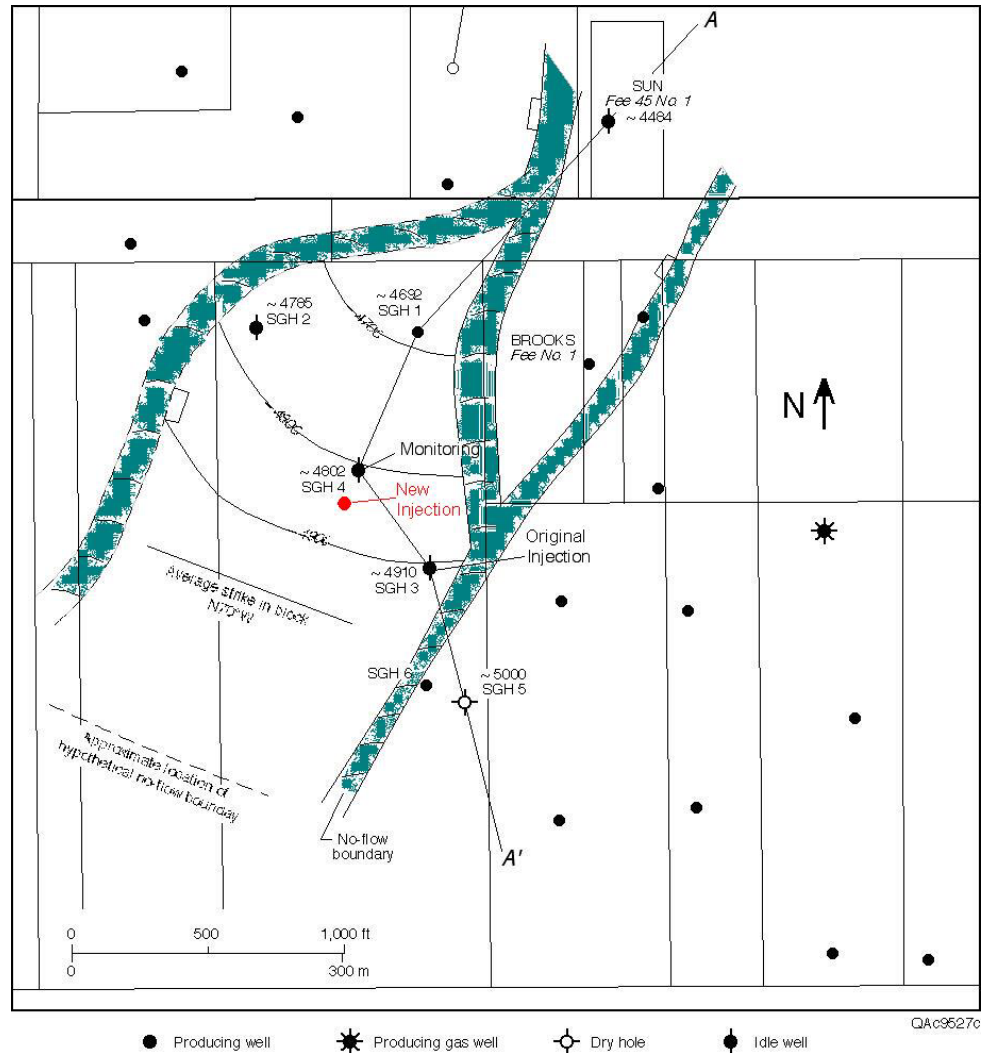

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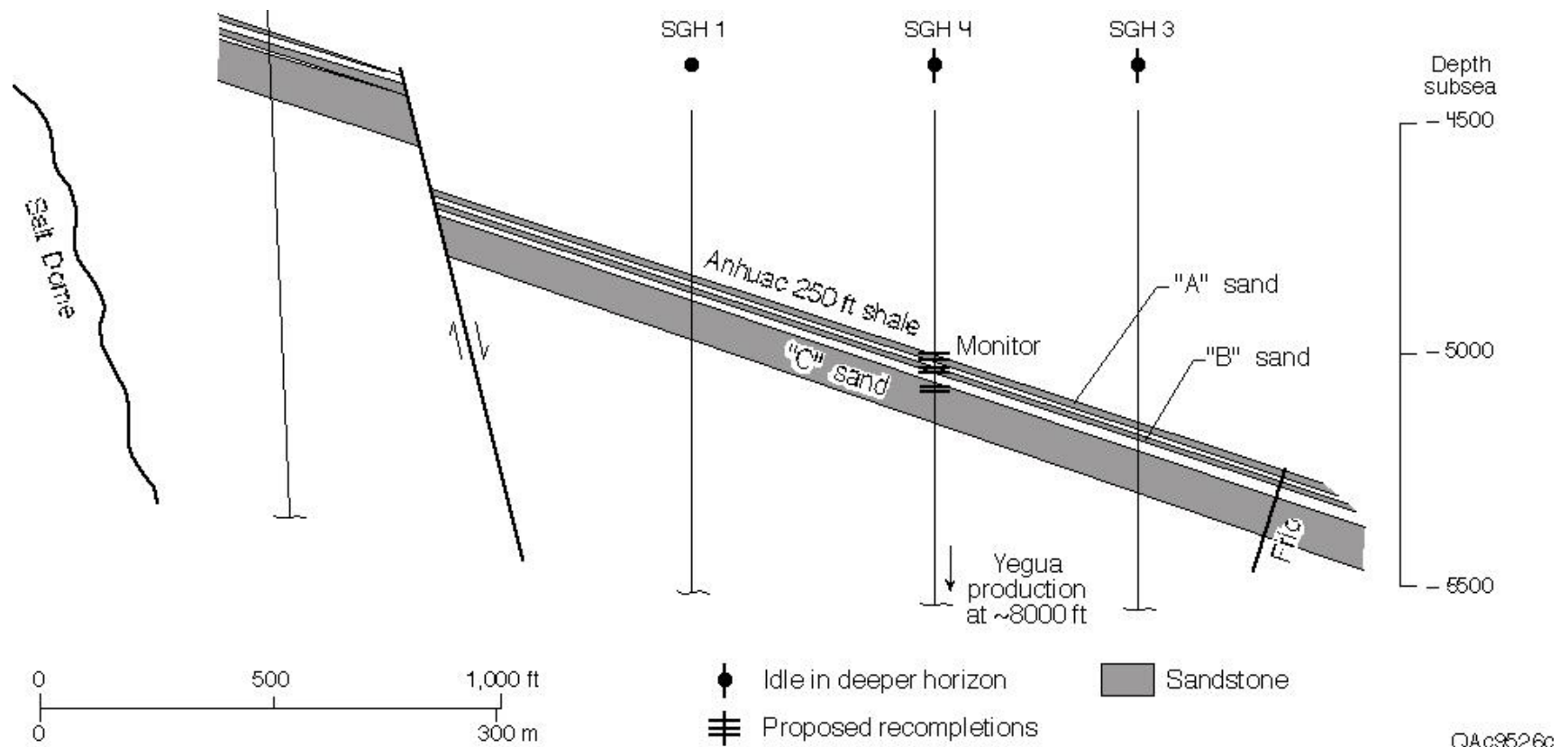
South Liberty Well Logs

- **A, B, C sands are all potential targets**
- **Shales believed to form vertical seals**
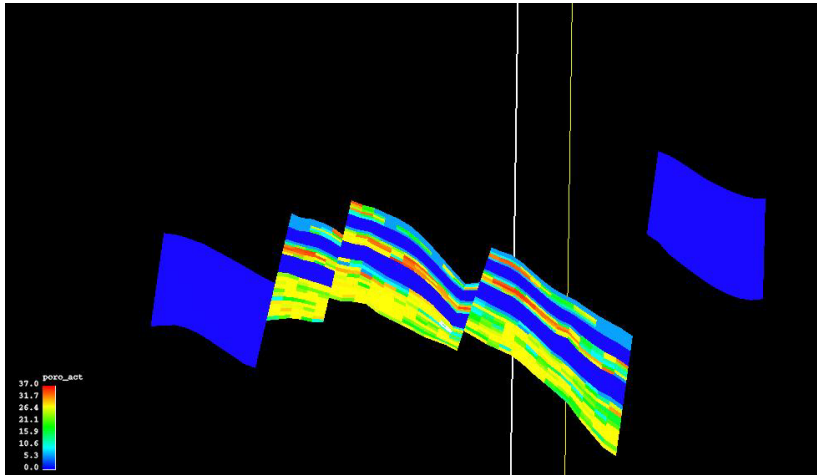- **Depth ~ 1500 m, CO_2 supercritical**
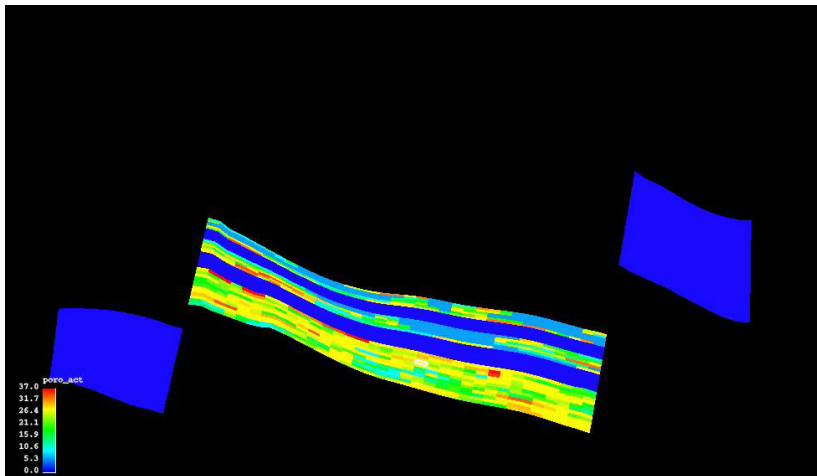- **No petroleum at these depths**
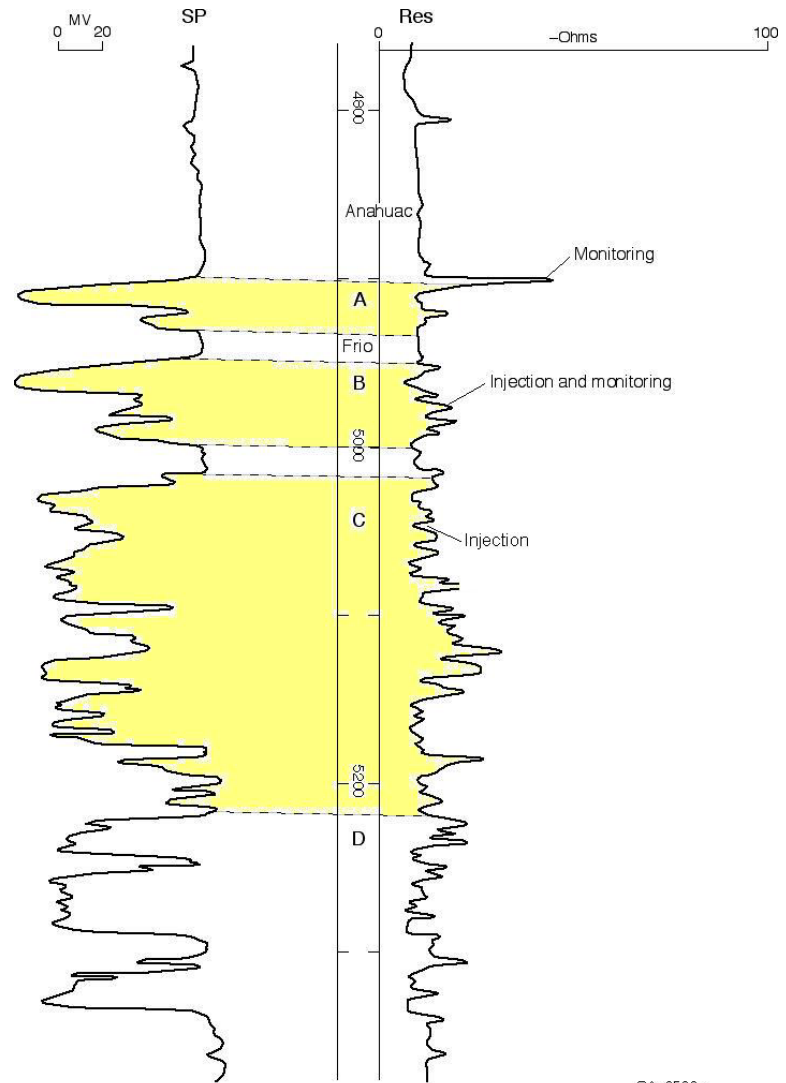
Fault Block Structure

- **Partially sealed compartment created by sub-vertical faults**

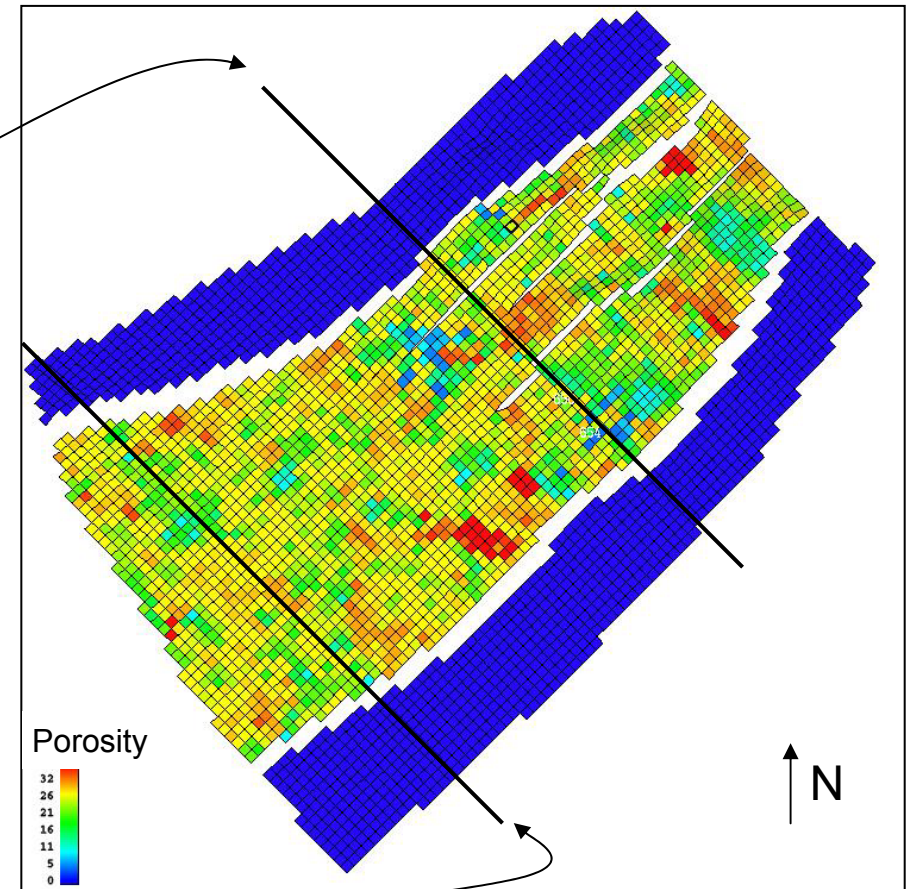- **15°dip (updip direction is NE, faults create potential trap)**

Intra-Fault-Block Structure

NW-SE cross-sections

Plan view: top of C sand

N

Purpose of Well-Testing Program

I.   Pre-test site characterization to address hydrogeologic uncertainty

II.   Plume monitoring during pilot

— Track movement of CO_2 plume

— Estimate two-phase flow properties

In each phase, coordinate with and complement well logging, geochemical sampling, and geophysical surveys

Hydrogeologic Uncertainty

- **Fault-block bounding faults: barriers or conduits for flow?**
- **Continuity of inter-sand shale layers**
- **Connectivity of sand layers across intra-fault-block faults**
- **In situ phase conditions**
  - **No gas**
  - **Dissolved gas**
  - **Immobile gas**
- **Flow and transport properties**

Well-Test Plan I

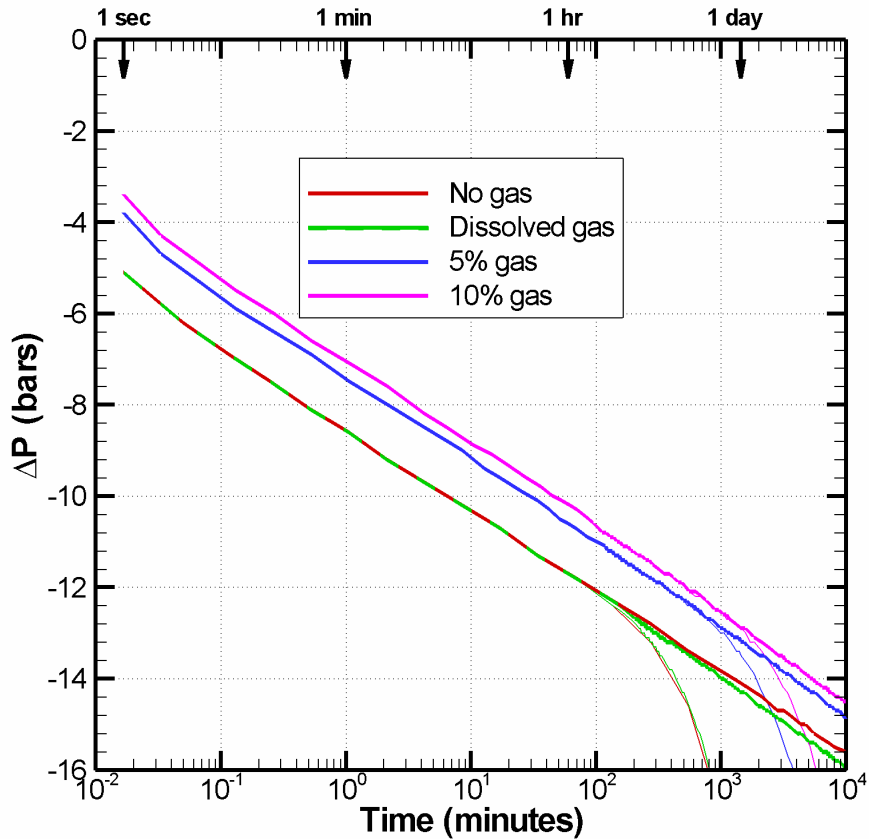| Pre-Test Activity	Purpose	Duration
None	Recovery period after completion of new well and workover of Well SGH-4; allow pressures and temperatures to return to undisturbed conditions	1-2 weeks
Pump test 1 Well SGH-4 C sand at 50 gpm	Decrease pressure around the well; look for evidence of exsolution of dissolved gas in P vs. t. Save water for subsequent injection test	1-2 days
Injection test 1 New well C sand at 50 gpm	Increase pressure around the well; look for evidence of dissolution of gas in P vs. t	1-2 days
Pump test 2 New well C sand at 50 gpm	Same as pump test 1. Compare responses of two wells	1-2 days
Injection test 2 Well SGH-4 C sand at 50 gpm	Same as injection test 1. Compare responses of two wells	1-2 days
None	Pressure recovery	2 weeks
Pump test 3 New well C sand at 5 gpm	Estimate kH, investigate boundary effects. Save water for possible CO_2 chaser	2 weeks
None	Pressure recovery	4 weeks

Well-Test Plan II

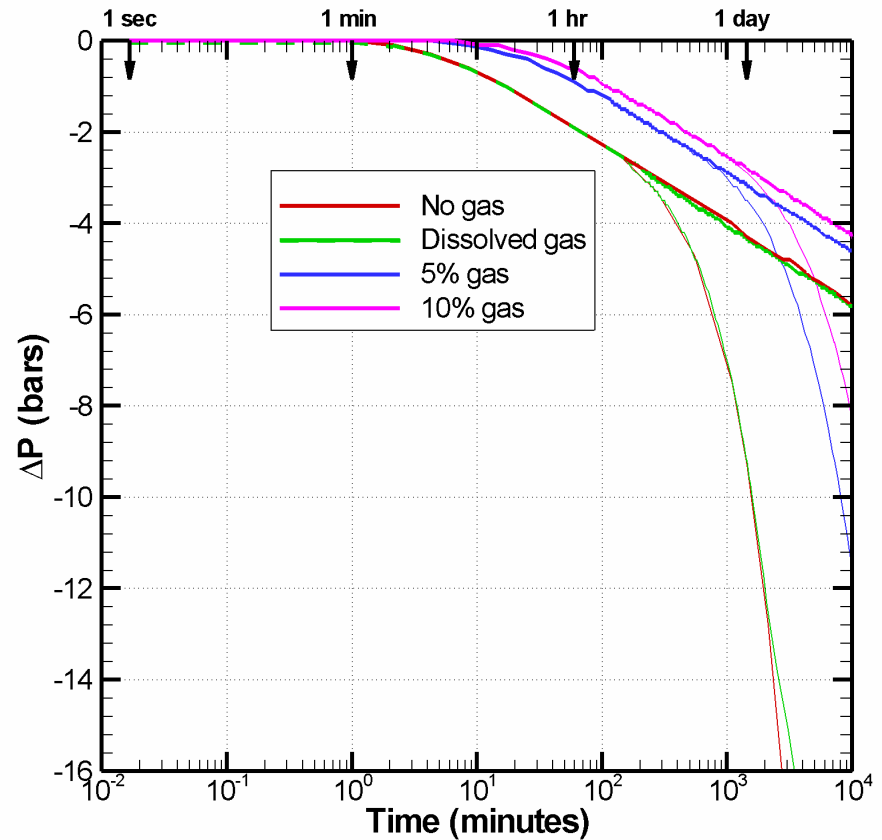| During-Test Activity	Purpose	Duration
Inject CO_2 at 250 T/day	Create a plume that does not reach monitoring well. Pressure-transients reflect single-phase liquid conditions	1 day
Rest	Allow pressure recovery, opportunity for geophysics	2-4 days
Inject CO_2 at 250 T/day	Create a plume that may reach monitoring well (or not). Pressure-transients reflect two-phase conditions	3 days
Rest	Allow pressure recovery, opportunity for geophysics	5 days
Inject CO_2 at 250 T/day	Create a bigger plume – try to make sure it reaches the monitoring well	11 days
Rest		
Inject formation brine at 5 gpm	If CO_2 has not reached monitoring well, try to get it there. If it has, study behavior of trailing edge of plume	2 weeks

Modeling Approach

- **Radial model for in situ phase studies**
  - —**Pump or inject in one well**
  - —**Watch pressure and saturation transients at active well and monitoring well location**
- **2D x,y model to study boundary effects, how wells respond to sequence of tests**
- **3D x,y,z model for shale contunuity, sand connectivity, CO_2 injection**
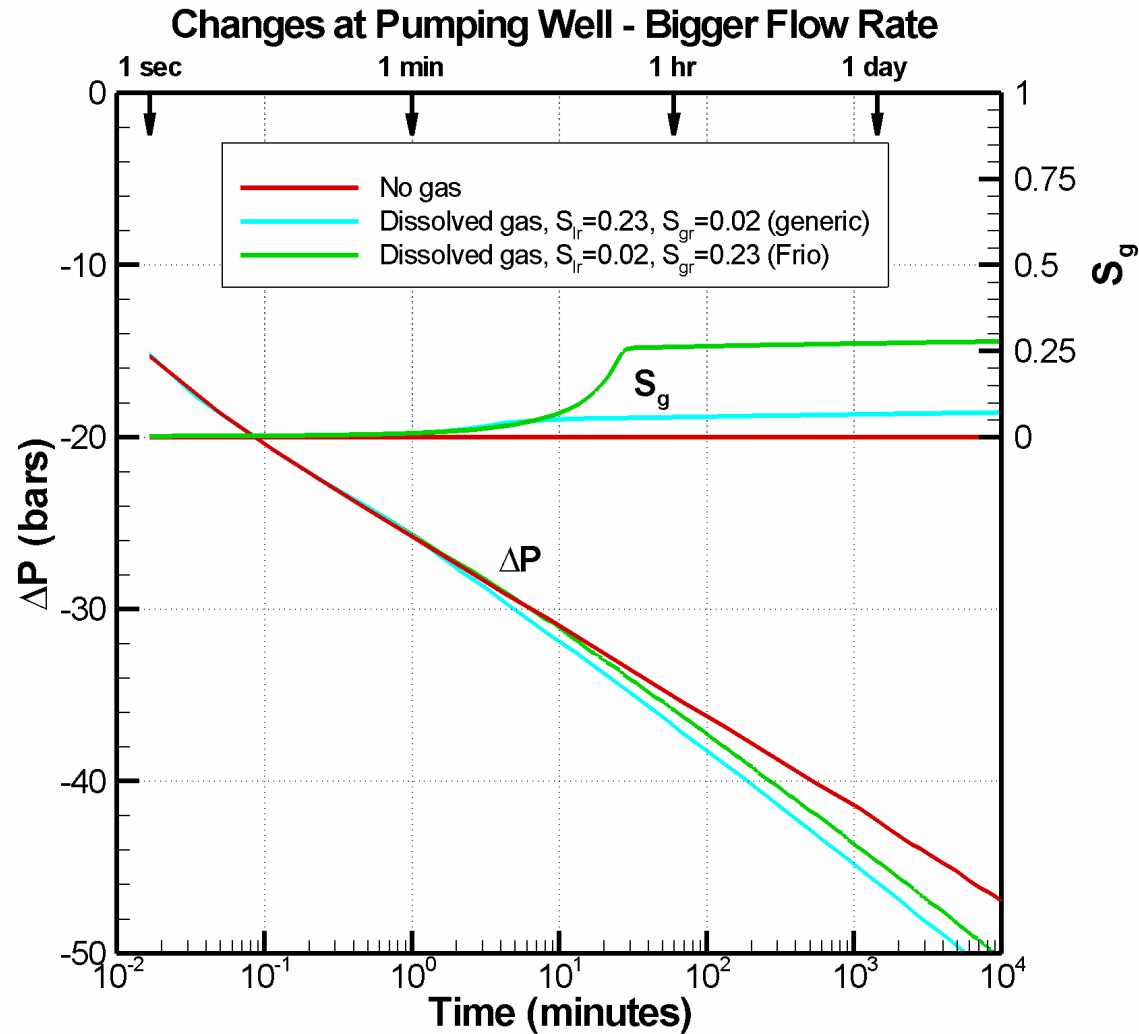
Radial Model Results – Pump Test

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Radial Model Results – Pump Test

Changes at Pumping Well - Bigger Flow Rate

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Radial Model Results – Injection Test

Pressure Change at Injection Well

1 sec   **1 min**   **1 hr**   **1 day**

Legend:
- No gas
- Dissolved gas
- 5% gas
- 10% gas

Y-axis: ΔP (bars), 0 to 16

X-axis: Time (minutes), 10^{-2} to 10^{4}
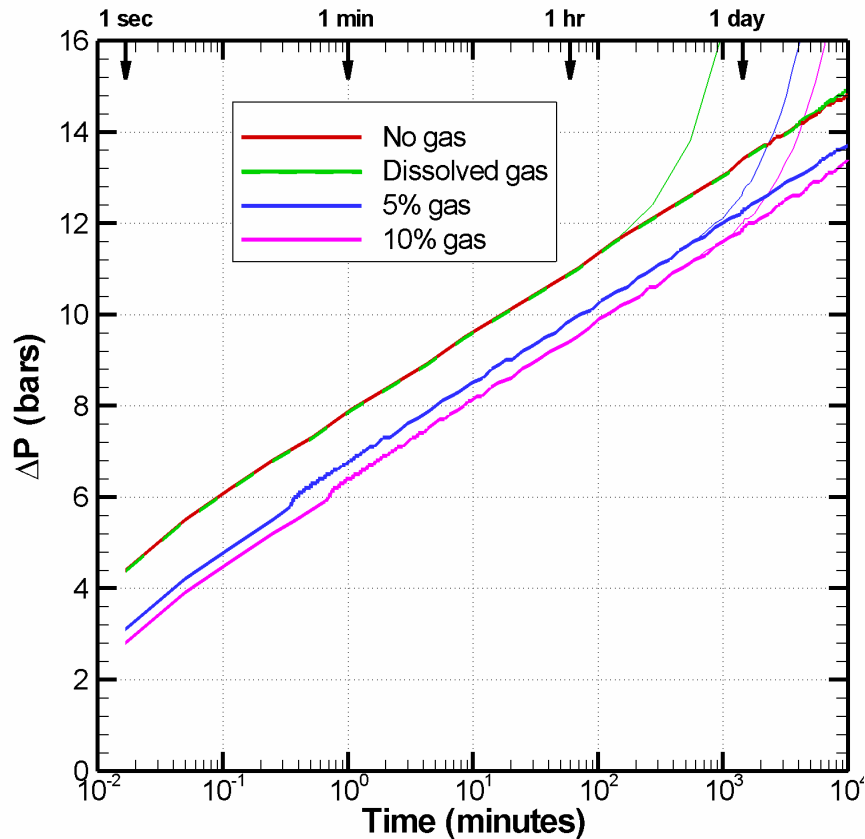
Pressure Change at 30 m Monitoring Well

1 sec   **1 min**   **1 hr**   **1 day**

Legend:
- No gas
- Dissolved gas
- 5% gas
- 10% gas

Y-axis: ΔP (bars), 0 to 16

X-axis: Time (minutes), 10^{-2} to 10^{4}

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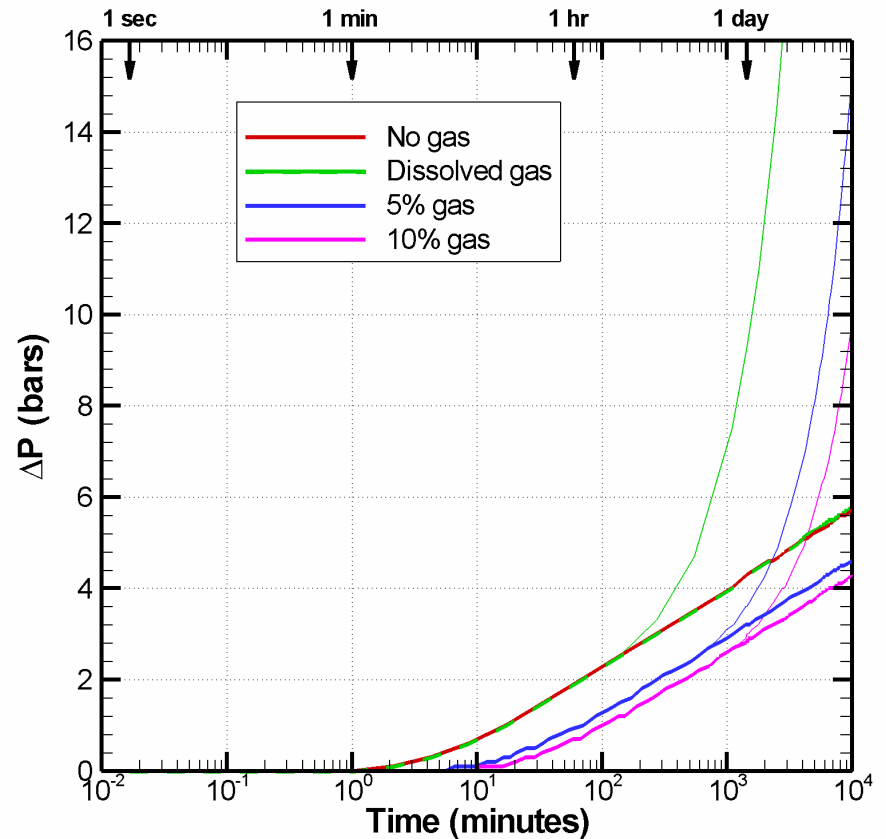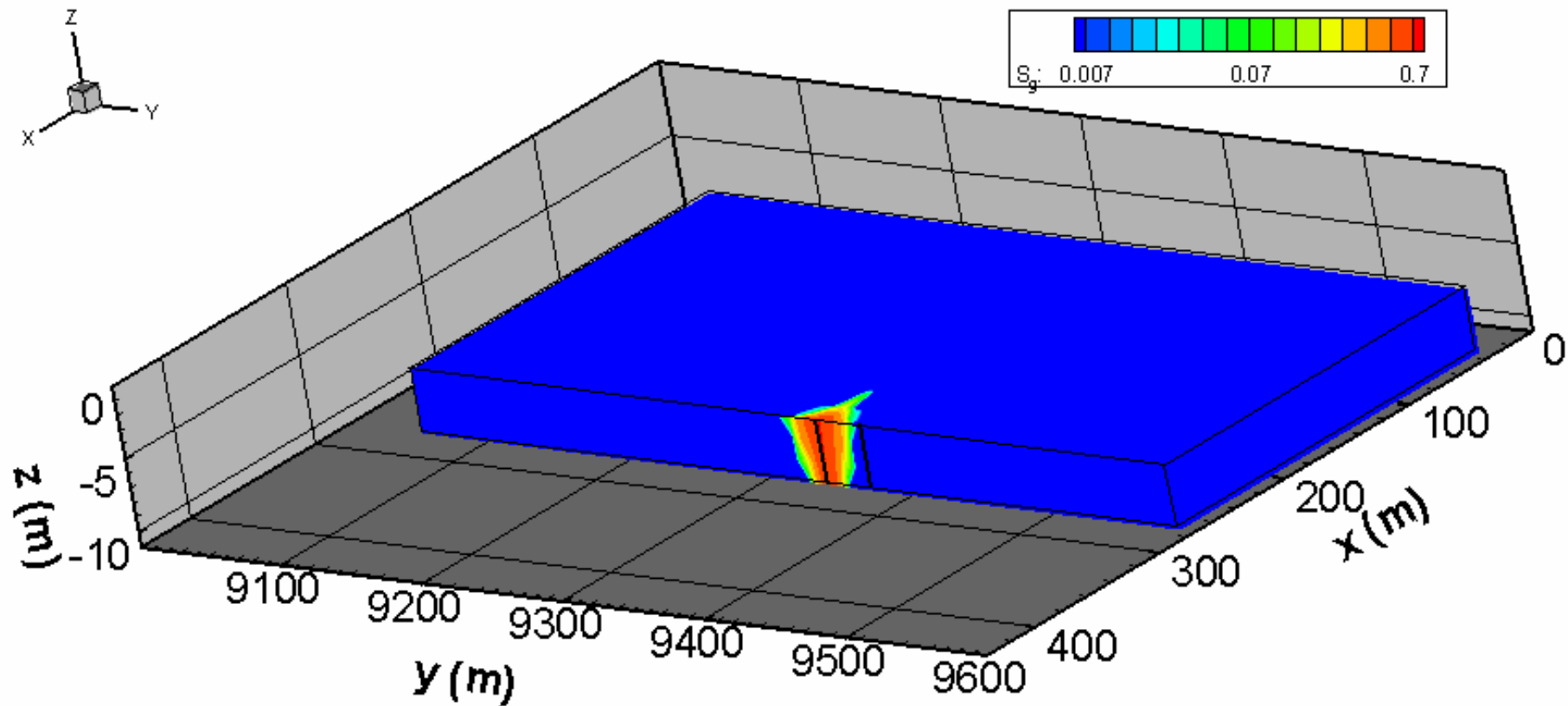
Example 3D Model Results
20 days of CO_2 injection, then rest for 1 year
generic relative permeability
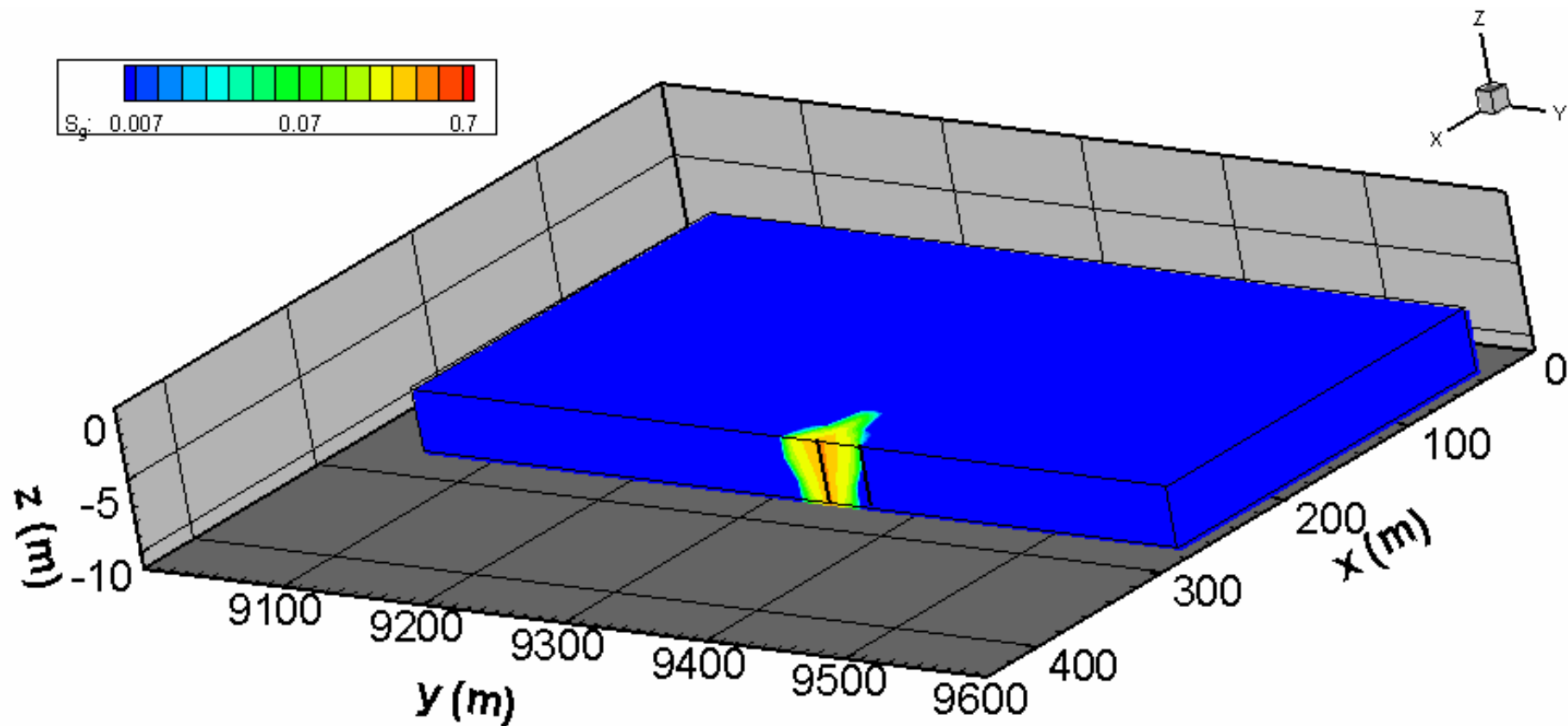
TOUGH2 Simulation: C. Doughty, Earth Sciences Division, Lawrence Berkeley National Lab.
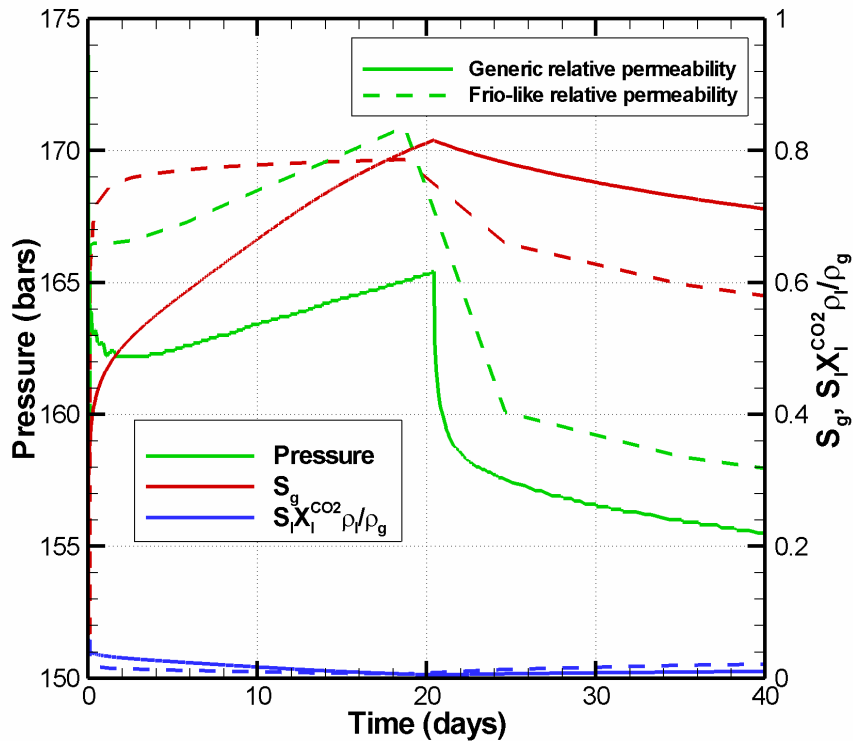
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Example 3D Model Results
20 days of CO_2 injection, then rest for 1 year
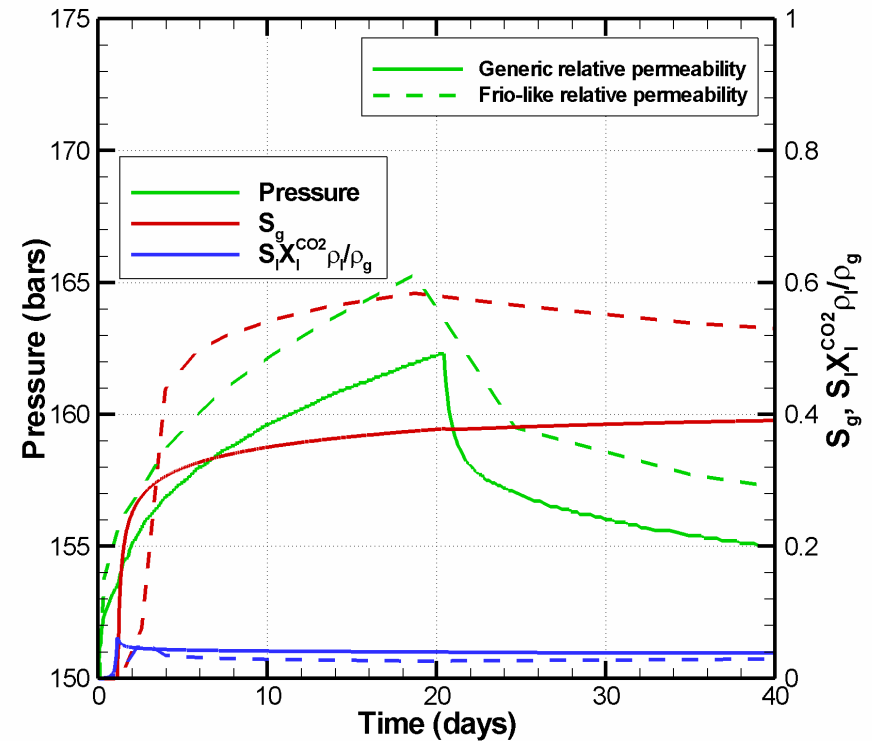## Frio-like relative permeability

TOUGH2 Simulation: C. Doughty, Earth Sciences Division, Lawrence Berkeley National Lab

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Example 3D Model Results

Response at Injection Well

Response at 30 m Monitoring Well

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Conclusions

- **Pre-test site characterization**
  - —**Lateral boundary conditions**
  - —**Shale continuity**
  - —**Sand connectivity**
  - —**In situ phase conditions**
  - —**Flow and transport properties**
- **During-test plume monitoring**
  - —**Track CO_2 plume**
  - —**Estimate two-phase flow properties**